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MICROSTRUCTURE INVESTIGATIONS IN THE BALTIC SEA  
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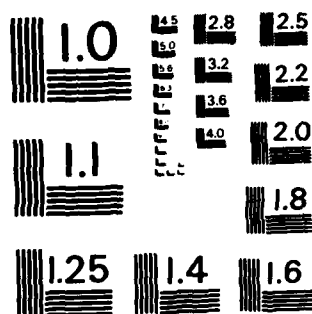
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# MICROSTRUCTURE INVESTIGATIONS IN THE BALTIC SEA

[Prandke, Hartmut, Dr.; Mikrostrukturuntersuchungen in der Ostsee; Seewirtschaft No. 2, 1983, pp. 91-96; German]

## 1. Introduction

/91

Since the beginning of scientific ocean research in the middle of the nineteenth century, the investigation of the vertical stratification of the water of the oceans and the seas has played a dominant role. Consistent with the state of knowledge and the technical possibilities, in the early decades of directed subject research of the oceans the "coarse structure" of the water stratification was determined. The main measuring instrument was the bottle with the reversing thermometer developed by Nansen. With that instrument, layer structures were able to be studied up to a resolution of about 5 m.

In the forties of this century, it was recognized that knowledge of the coarse structure of the water stratification is not enough to explain many processes in the sea. Thereafter, especially in the fifties and the sixties, electronic measuring probes were therefore developed in a whole list of oceanological institutes which can record the fine structure of the density stratification, that is the vertical profiles of the temperature, the electrical conductivity, and other parameters, up to a resolution of a few decimeters. Those STD (salinity, temperature, density) probes are today the main measuring instruments of oceanologists worldwide. Also in the forties it was discovered that superposed over the layer structures in the fine structure range (a few meters to a few decimeters) is another microstructure in the decimeter to millimeter range. The connection between coarse, fine, and microstructure is shown in fig. 1 by way of an example of the water stratification in the western Baltic Sea (Mecklenburg Bay).

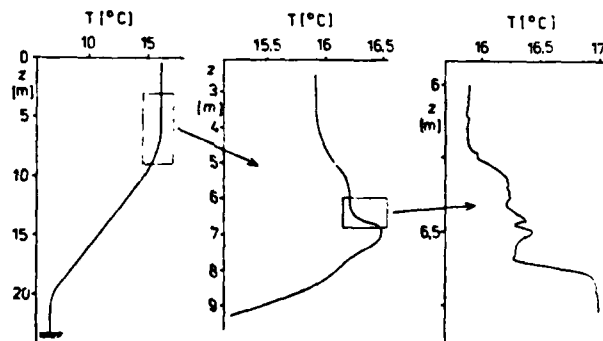


Fig. 1. Coarse, fine, and microstructure of the water stratification by way of an example of the vertical profile of the temperature at a station in Mecklenburg Bay, measured on 16 July 1981

The causes of the microstructure lie in the dynamic processes in the body of water which are operating especially in the area of the internal

\*Numbers in right margins indicate pagination in the original text.

boundary layers (temperature and salinity discontinuity layers). The internal waves generated here by various processes can become unstable and break. As a result of those incidents of breaking, vertically limited area result with markedly turbulent mixing, so-called microstructure patches, with characteristic time scales of a few minutes. From those mixing processes and after the active turbulence subsides there result homogeneous layers from a few decimeters up to a few meters in thickness, which are also designated as "fossil turbulence." The individual homogeneous layers are separated from one another by layers with sharp changes in temperature and salinity (sheets). The resulting "conventional" density stratification, which was detected in the open sea and in its adjacent seas, and also in inland seas, (e.g., /1/, /2/, /3/), is relatively stable. In the open sea the existence of such structures has been demonstrated over weeks. In the Baltic Sea the resulting stratification structures are being altered in a substantially shorter time by new breaking incidents and by other dynamic processes. The characteristic time scales for stratification structures in the fine and microstructure range are in the range of minutes to hours, and in the open sea, possibly even in the range of a few days.

Besides this "conventional" process of development, also the seaway, disturbances in the current field (e.g., undersea ridges) and double diffusion processes, which originate in the variable diffusion velocities of temperature and dissolved salts in water, result in the distinctness of the microstructure in the vertical density stratification of water. The investigation of the microstructure is of great interest for many branches of oceanology. It is of fundamental importance for the understanding of the mixing and stratification processes at work in the sea. Investigations of the properties of the microstructure as well as the causes of their origin are necessary in that regard. Of special importance is the knowledge of the microstructure for the study of energy dissipation in the ocean, especially for the investigation of the turbulent energy and matter transport through boundary layers, for the investigation of the vertical propagation of subsurface plankton populations as well as for the determination of the sound propagation conditions in the layered and unlayered bodies of water. This also holds true to an even greater degree than for the open sea for the Baltic Sea, since here the whole hydrographic regime is determined by a marked thermohaline stratification (see e.g. /4/). In that respect investigations of the microstructure and the associated dynamic processes primarily in the discontinuity layers are of great interest for practically all branches of Baltic Sea oceanology.

The first investigations of the fine and microstructure of the thermal density stratification are from the years 1943-44. They were to examine the sound propagation conditions in the Baltic Sea more closely. The results of these investigations, which were conducted with very simple means (unprotected thermocouples and reflecting galvanometer with photographic recording) are reported in /5/. Also conducted with simple thermocouples were microstructure investigations of Urlick and Searfoss /6/ off the coast of Florida. Other early investigations of microstructure by Liebermann /7/ and Frassetto /8/ are known. In the late sixties there began an intensive study of the microstructure of the oceans and of their adjacent seas on the international level. Moreover, a series of special microstructure probes

were developed and employed, which measure the temperature, the electrical conductivity, and the current shear or only one or two of those parameters. Those probes differ from the ship-mounted STD probes (e.g., OM 75 of the Institute of Oceanology) in that they drop freely in the water, being separated from the rolling motions of the ship, and permit a high spatial data resolution. The microstructure probes known from international literature attain vertical resolutions of the temperature of 1 mm, of the electrical conductivity of 10 mm, and of the current shear, of about 5 mm. The mean dropping speed is a few decimeters per second. The data recording is on suitable data carriers (e.g., MB cassettes) either directly in the probe or aboard the research ships. In the latter case, the data are transmitted over fine cables, which influence the dropping speed not at all, or only insignificantly. Those instruments designed for the open sea have operating depths of a few tens of meters to over 1000 m. /92

Proceeding from the tasking within the framework of Baltic Sea research, at the Institute for Oceanology of the Academy of Sciences of the GDR a measuring probe was developed for investigating the microstructure of the vertical density stratification in the Baltic Sea and built as UNIKAT, and with which the temperature and the electrical conductivity were recorded. From those two values can be calculated all the other parameters which are important for the formation of the stratification of the water (such as salinity and the density of the sea water). Consistent with the special hydrographic conditions in the Baltic Sea (marked thermohaline layer) and the planned operating conditions, special requirements departing from those of the familiar probes had to be taken into account in the development of this microstructure probe (MSS-Mikrostruktursonde - microstructure probe). While the probes made for oceanic use must record over the greatest possible depth ranges, the MSS is provided mainly for probing depth ranges with marked density discontinuity layers, therefore for depth intervals of limited size (about 10 m) up to depths of 100 m. In the process, equally high demands must be placed on the vertical data resolution of the sensors for recording the temperature and the electrical conductivity. From various microstructure studies (e.g., /1/ and /9/) it is known that the smallest layer structures in the discontinuity ranges have dimensions of 1 to 2 cm. In order to record such structures as authentically as possible, the two sensors must exhibit a spatial resolution in the order of magnitude of a millimeter, whereby their dynamic response behavior (reaction and data alternations) must be practically identical in order to avoid errors in the calculation of the salinity, the density, and other parameters. Owing to the relatively sharp temperature and electrical conductivity changes in the discontinuity regions of the Baltic Sea, not as high demands must be placed on the data resolution of the sensors as on probes for oceanic use. Data resolutions of 0.01 K for the temperature and 0.01 mS/cm for electrical conductivity are adequate for carrying out the planned task.

## 2. Structure and Function of the MSS Microstructure Probe

The main structural elements of the MSS are the underwater unit with the two sensors for temperature and electrical sensitivity, the onboard unit, and the boom. To complete the measuring system, an echo sounder, the KSR 4100 minicomputer integrated in the OM 75 oceanologic data network including

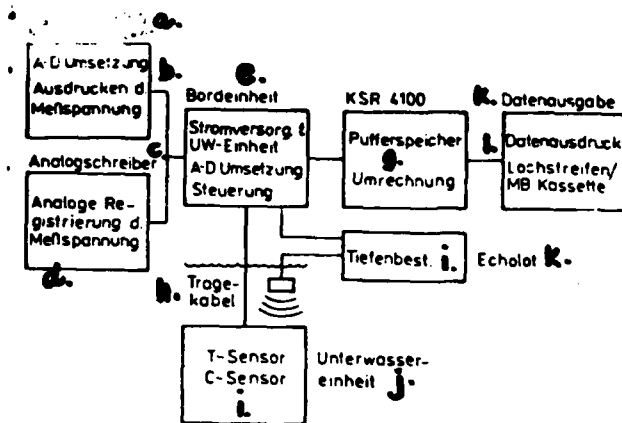


Fig. 2. Block diagram of the MSS microstructure probe including peripheral equipment

- a. Digital voltmeter/Data logger
- b. A-D conversion
- c. Printout of measuring voltage
- d. Analog recorder
- e. Analog recording of measuring voltage
- f. Onboard unit
- g. Power supply for underwater unit
- h. A-D conversion
- i. Control
- j. Buffer store
- k. Conversion
- l. Suspension cable
- m. Depth determination
- n. Underwater unit
- o. Echo sounder

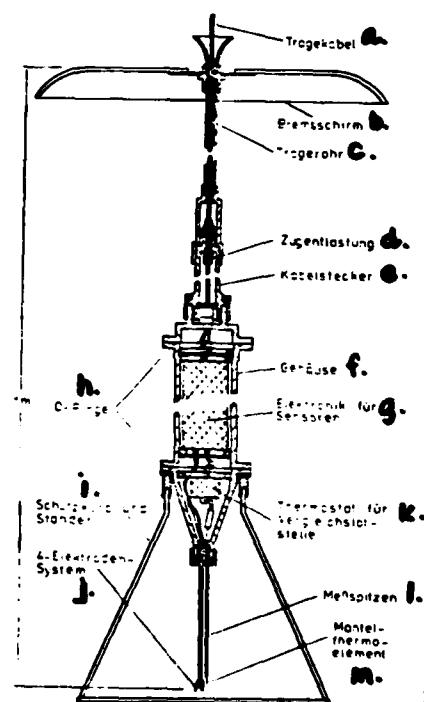


Bild 2. Block-schaltbild der Mikrostruktur-sonde MSS einschließlich der peripheren Geräte

Fig. 3. Cross section of the underwater unit of the MSS microstructure probe

- a. Suspension cable
- b. Drag chute
- c. Tube
- d. Strain release
- e. Cable plug
- f. Casing
- g. Electronics for sensors
- h. O-rings
- i. Basket shield and frame
- j. 4-electrode system
- k. Thermostat for comparative soldered junction
- l. Measuring tips
- m. Shielded thermocouple

Bild 3. Schnitt-darstellung der Unterwasser-einheit der Mikrostruktur-sonde MSS

its peripheral equipment or a digital voltmeter/data printing system, are needed. Fig. 2 shows a block diagram of the entire measuring installation.

## 2.1. Underwater unit

The construction of the underwater unit can be seen in the cross sectional drawing in fig. 3. It consists essentially of a watertight casing which at the bottom has two measuring tips and one basket shield (which serves as a frame at the same time) and at the top is connected to a rigid drag parachute by means of a cable plug and a tube. The casing parts, the basket shield, the measuring tips, the cable plug, and the tube are made of brass. The drag parachute consists of seawater-resistant thermoplastic.

The underwater unit is dimensioned such that it drops at a constant average velocity of 0.5 m/s. In that way its vertical motion is uncoupled from the rolling motions of the ship. Depth recording is accomplished with an echo sounder, whose oscillator must be located precisely over the probe. This type of depth measurement in microstructure probes is being used here for the first time. It has the advantage over pressure sensors that it can be made practically without any own development costs, and works with great precision especially in the area of the top layer (a few meters to about 100 m). To prevent lateral drifting during the measuring process, the probe is held vertical by a pair of taut guy wires (see fig. 7). In designing the underwater unit, care also had to be taken that during the dropping process no disturbance or deformation of the vertical profile to be probed can occur from the probe itself. From photography of streamer bodies it can be seen that disturbances of the layer structures set in ahead of the body at about the distance of its diameter. In the MSS underwater unit there are therefore the two measuring sensors which are carried by the measuring tips at a distance of about twice the diameter of the various streamer diameters (casing flange, drag parachute).

## 2.2. Temperature sensor

In most of the known microstructure probes, encased miniature thermistors of various design are used as the temperature-sensitive elements. They exhibit a high temperature resolution as well as relatively short response times, and therefore make possible vertical data resolutions to 1 mm. Temperature sensors based on a thermistor described in /10/ attain a data resolution of a few micro-degrees. According to investigations by Gregg and Meagher, the response times of those highly sensitive thermistor sensors is at 20 ms during current velocities of 0.1 m/s to about 20 m/s. Also unprotected Chromal-Constantan thermocouples were used by Caldwell among others besides thermistors, but they had a life of only one to three days at sea /11/.

In designing the temperature sensor for the MSS microstructure probe, they proceeded from the fact that miniature thermistors as well as unprotected thermocouples as sensors for temperature did not fully satisfy the requirements set. With respect to the electrical and thermodynamic parameters, miniature thermistors are admittedly very well suited, but their manufacture presents some difficulties, since the commercially available thermistors are too large and therefore exhibit long response times. The weight of those



thermistors and therefore also their response time, must be reduced to the necessary level. Measuring sensors produced in that manner are, however, extremely sensitive to mechanical stresses and therefore--especially during unfavorable weather conditions--only conditionally suited for routine measuring work. Unprotected thermocouples are precluded, owing to their too short life when used at sea.

A shielded thermocouple was therefore used as a temperature sensor for the MSS microstructure probe. Such temperature sensors are watertight and corrosion-proof as well as mechanically, chemically, and electrically completely shielded from external influences. They consist of a small fine-steel tube welded closed at one end, in which there is a thermocouple with the soldered junction in the welded end. The two wires are electrically insulated from the steel casing. The insulation resistance is a few megaohms. The shielded thermocouple (made by VEB Walzwerk Hettstedt) used in the MSS has an outside diameter of the shield of 0.5 mm. The temperature-sensitive point is about 1 mm long. The response time in water is about 30 ms. The reference temperature (temperature of the junction) is generated by an electronically regulated thermostat of high quality. The measuring voltage supplied by the shielded thermocouple, which corresponds to the temperature difference between the water temperature at the junction and the reference temperature, is electronically intensified and transmitted via the suspension cable to the onboard unit. Fig. 4 shows a block diagram of the temperature sensor.

### 2.3. Conductivity sensor

Various systems are employed in microstructure probes as sensors for measuring electrical conductivity. Woods /12/ used a simple 2-electrode system. A special 4-electrode system with improved vertical data resolution was developed by Greeg and Cox /13/, which was also used in other microstructure probes. A real vertical resolution of the electrical conductivity below 1 cm, however, cannot be attained with these systems. The employment of the induction method for measuring electrical conductivity in the microstructure range has not produced good results /14/. Since the required spatial data resolution cannot be attained in the millimeter order of magnitude with these known solution options, a new conductivity sensor had to be developed for the MSS microstructure probe. A detailed description of this sensor is given by Krueger and Prandke in /15/.

The MSS conductivity sensor consists of a 4-electrode system, an oscillator, and multistage electronic switching to prepare the measuring voltage. Fig. 5 shows the block diagram of the sensor. The dimensions of the electrode system are selected so that a vertical data resolution of about 1 mm is possible.

The external electrodes (field electrodes) of the 4-electrode system are fed from an oscillator with a constant alternating current. Depending on the electrical conductivity in the measuring medium, a voltage is set up between the two interior electrodes (measuring electrodes) which is tapped off by the filter amplifier tuned to the oscillator frequency. The filter amplifier suppresses spurious signals of another frequency, especially 50-Hz interference. The AC voltage signal is then conducted to a voltage current converter and, through it, converted to a proportional AC signal.

This AC signal is converted into a pulsating DC voltage by the next current rectifier. By using the voltage current converter/current rectifier combination for rectification, the non-linear characteristics of the rectifier diodes and their characteristic differences and changes are left without any effect on the transfer characteristic of the rectification. The following low-pass filter (integration unit) reduces the residual rippling to a minimum dependent on the oscillator frequency and the low-pass time constants. The DC voltage supplied at the deeppass filter is converted by another voltage current converter into a proportional direct current of 0 to 5 mA and fed into the suspension cable.

#### 2.4. Onboard unit

The onboard unit is the central control unit of the MSS. Its fundamental structure is shown in the block diagram (fig. 6). The onboard unit has the following functions:

- current supply for the underwater unit
- time control of the measuring process
- conversion of the analog measuring voltages into dual 12-bit words.

Bild 4. Blockschaltbild des Temperatursensors der Mikrostruktursonde MSS

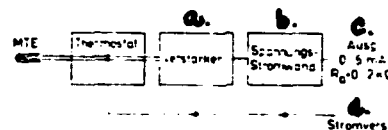
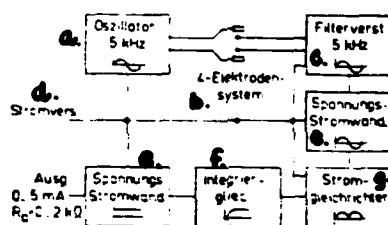


Fig. 4. Block diagram of the temperature sensors of the MSS microstructure probe

Bild 5. Blockschaltbild des Leitfähigkeitssensors der Mikrostruktursonde MSS



a. Amplifier b. Voltage current converter c. Output d. Current supply

Fig. 5. Block diagram of the conductivity sensor of the MSS microstructure probe

Bild 6. Blockschaltbild der Bordeneinheit der Mikrostruktursonde MSS

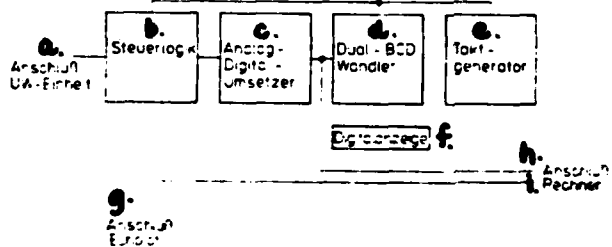


Fig. 6. Block diagram of the onboard unit of the MSS microstructure probe

a. Underwater unit connection b. Control logic c. Analog-digital converter d. Dual BCD converter e. Timing

generator f. Digital indicator g. Echo sound connection h. Connection i. Computer

- transmission of the dual 12-bit words to the KSR minicomputer for storage and further processing
- digital indication of the converted measuring voltages.

In the onboard unit the data supplied by the underwater unit in the form of 0...5mA direct currents per measurement channel are converted into 0 to 5 V measurement voltages with the aid of load resistors. Those voltages are converted into dual 12-bit words in fixed set intervals (pulse frequency) and transmitted to the KSR 4100 computer. Correspondence between the onboard unit and the computer is with standard interface SI 1.2. The pulse frequency can be varied between 2 ms and 1 s in seven steps. With an average fall velocity of the probe of 0.5 m/s, vertical data resolution of 1 mm to 0.5 m are therefore possible. The conversion of the measuring voltages in channel E1 (temperature) and in channel E2 (electrical conductivity) is performed in sequence with a time interval of 60  $\mu$ s. Since that sequential transfer of the temperature/conductivity data pairs is performed sufficiently rapidly, it does not cause measurable errors in the depth coordination. During a time period of 60  $\mu$ s the probe has fallen a negligibly small distance of 30  $\mu$ m.

The digitalized data voltages transmitted to the computer during the probe, a maximal 500 temperature/conductivity data pairs per second, are first stored in the main store of the computer. After the probe, which itself has lasted only a few seconds, is completed, the stored measurement voltages are converted into absolute values of the temperature and of the electrical conductivity and delivered to a magnetic tape cassette. If necessary, there can be a printout of the measurement series immediately on board. Further processing of the data on the magnetic tape cassettes, especially identification and elimination of outliers as well as dynamic correction, with which the inertia of the measuring system (response behavior) is compensated in order to attain an objective vertical data resolution in the millimeter order of magnitude, is performed on the ES 1010 computer installed at the Institute of Oceanology.

If a linking of the MSS with the KSR 4100 or any other suitable computer is not possible (e.g., work done on a charter ship), then the data recording can be performed also with a digital voltmeter and data printer, whereby the attainable vertical resolution is determined by the working speed of this system. Analog recording of the data on a 2-channel analog recorder is possible concurrently with the digital data recording with the existing computer connection as well as when measuring with a digital voltmeter/data printer.

## 2.5. Measurement sequence with the MSS microstructure probe

Owing to the special operating conditions in the Baltic Sea, the sequence of a probe with the MSS is different from that with freely falling probes used in the ocean. With those probes, the falling process, which can last hours with corresponding operating depths, begins immediately after being lowered by the research ship. After reaching a prescribed depth or after a prescribed falling time, the surfacing process is initiated automatically or by means of an acoustic releaser. This can be done by releasing ballast weights and also by filling buoying devices with compressed air. When the probes have reached the surface, a radio transmitter is switched on, which permits getting a fix on finding the device. This operating sequence of vertical probes, which requires great technical resources, is hardly possible

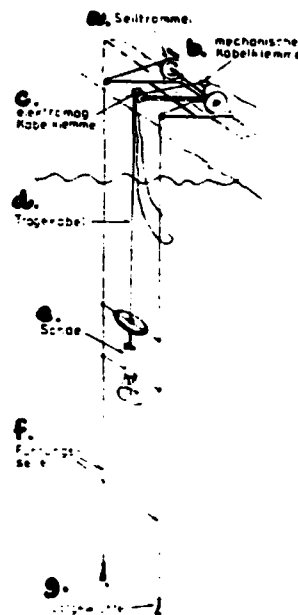


Bild 7. Der Ausleger mit der Unterwasserinheit der MSS. Die Sonde ist vorbereitet für eine Sondierung. Dazu wird sie am Tragkabel von der elektromagnetischen Kabelklemme oberhalb des zu untersuchenden Tiefenbereiches gehalten. Die Länge der freihängenden Tragkabelschleife entspricht der Länge des Sinkwegs der Sonde.

Fig. 7. The boom with the underwater unit of the MSS. The probe is ready. Moreover, it is held on the suspension cable above the depth range to be studied by the electro-magnetic cable clamp. The length of the free-hanging suspension cable loop corresponds to the length of the drop path of the probe.

a. Wire drum b. mechanical cable clamp c. electromagnetic cable clamp d. suspension cable e. probe f. guide wire g. weights

Bild 8. Echo sounderaufzeichnung einer Sondierung mit der Mikrostruktursonde MSS

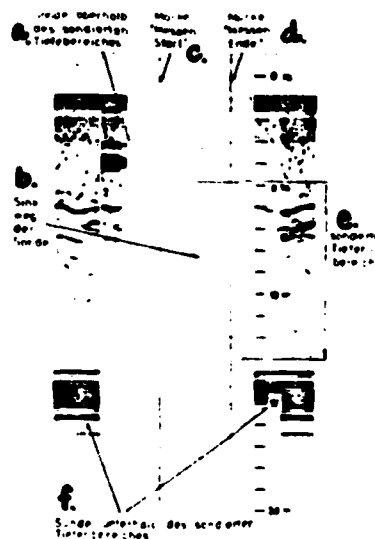


Fig. 8. Echo sound recording with the MSS microstructure probe

a. probe over depth area to be studied b. fall path of probe c. mark "start measuring" d. mark "end measuring" e. depth area probed f. probe below depth area to be studied

or even necessary in the Baltic Sea, owing to the shallow depths, if by priority selected depth intervals of limited size are to be surveyed. With the MSS the measuring sequence therefore proceeds in the following manner (fig. 7):

The probe is held somewhat over the depth range to be probed with the aid of the electromagnetic cable clamp of the boom on the suspension cable. The suspension cable is then set with the mechanical cable clamp of the boom according to the planned terminal depth of the falling process. The length of the free hanging cable loop between the electromagnetic and the mechanical cable clamp thus corresponds to the length of the fall path. The fall process of the probe begins with the release of the cable from the remote-controlled electromagnetic cable clamp. The vertical movement of the probe is recorded by the echo sounder. Fig. 8 gives an example. If the upper limit of the depth range of interest is reached, the analog-digital conversion of the measuring voltages and their transmission to the computer are also started by remote control. That point in time is automatically identified by a mark on the echogram. After the lower limit of the depth range is reached, the recording of the measuring voltages is stopped and another mark is made on the echogram. After the probe is ended, the probe continues to fall according to the paid out length of the suspension cable. The starting and ending depths of the probed depth range can be determined from the points of intersection of the fall path of the probe on the echogram with the start and end marks. Since the probe falls at a sufficiently constant velocity, all recorded data can be assigned to the corresponding measured depths simply and without ambiguity. /95

### 3. Early Measurement Results

The MSS microstructure probe was successfully employed in 1981 and 1982 on several oceanologic expeditions on the research ships ALEXANDER VON HUMBOLDT and PROFESSOR ALBRECHT PENCK of the Academy of Sciences of the GDR. All in all, several hundred probes were carried out in the months from May to September. Here we shall present a few characteristic results from the large volume of available data material now undergoing extensive scientific processing, which naturally cannot provide a complete and final picture of the microstructure of the summer water stratification in the Baltic Sea.

If we first consider the temperature and salinity discontinuity layers as a whole, then they appear as depth ranges of a few decimeters up to a few meters in thickness, within which one of those two both parameters change very sharply. This change occurs "smoothly" in the rarest cases, but generally takes place in a very irregular manner. Thus depth ranges with a great change (sheets) alternate with depth ranges with slight gradients (layers). The thickness of the sheets varies between a few centimeters and a few decimeters, while the thickness of the layers is on average between one decimeter and one meter. In fig. 9 is given a characteristic example for that "basic structure" of density discontinuities, whose origin was discussed in the introduction. Also already mentioned in the introduction is the rapid change in the fine and the microstructure despite an unaltered coarse structure of the water stratification in the Baltic Sea (fig. 10).

The detection of the mixing process in its initial phase, that is the recording of microstructure patches in the discontinuity areas of the open Baltic Sea, occurred very rarely, since those processes occur here only very sporadically. By contrast, in the sea areas with marked current shear, in which substantially more kinetic energy is available for the "mixing work," e.g., in the area of the Darss Shelf, such "active" layer structures were frequently found in the depth area of the discontinuity layers (fig. 11).

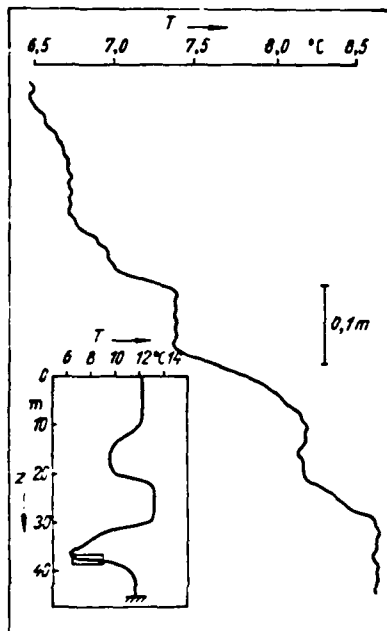


Bild 9. Ausschnitt aus einer bodennahen Temperatursprungschicht im Zentrum der Arkonasee, gemessen am 20. Juni 1981. Der „stufenförmige“ Aufbau der Sprungschicht ist deutlich erkennbar.

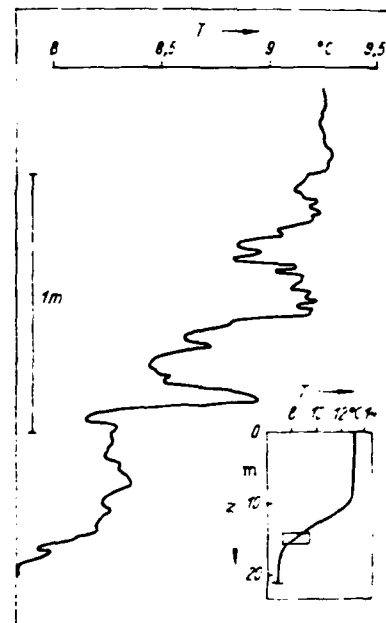


Bild 11. Temperaturprofil einer aktiven Vermischungszone (Mikrostrukturpatch) innerhalb einer breiten thermohalinen Sprungschicht im Gebiet der Darßer Schwellen gemessen am 14. Juli 1982.

Fig. 9. Section of a temperature discontinuity layer near the bottom in the center of the Arkona Sea, measured on 20 June 1981. The "step" structure of the discontinuity layer is clearly discernible.

Fig. 11. Temperature profile of an active mixing zone (microstructure patch) within a wide thermohaline discontinuity layer in the area of the Darss Shelf (measured on 14 July 1982).

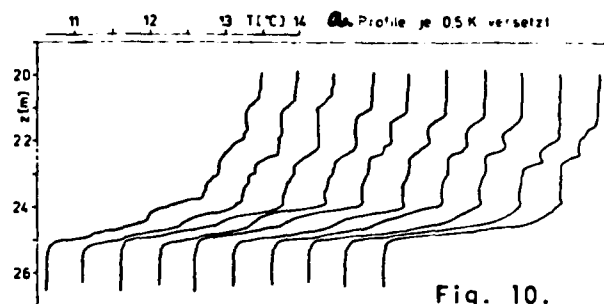


Fig. 10.

Bild 12. Vertikalprofile der Temperatur und des Salzgehaltes einer scharfen thermohalinen Sprungschicht ohne innere Struktur während einer Starkwindperiode in der Mecklenburger Bucht (gemessen am 14. Juni 1981)

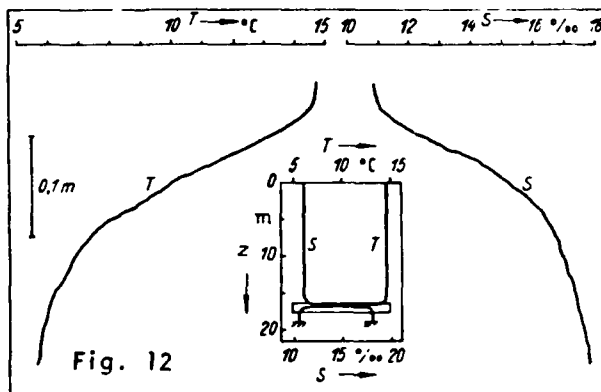


Fig. 12

Fig. 10. Vertical profiles of the temperature of a thermohaline discontinuity layer in Mecklenburg Bay. Measured in 10-min intervals on 26 September 1980. Also visible during the sharp temperature discontinuity at 25 m as well as in the depth range of 21 to 23 m is the rapid time change in the microstructure of the layers despite an unaltered coarse structure.

a. Profiles every 0.5 K

Fig. 12. Vertical profiles of the temperature and of the salinity of a sharp thermohaline discontinuity without internal structure during a period of strong breezes in Mecklenburg Bay (measured on 14 June 1981).

Under special hydrographic conditions, layer structures sharply departing from the basic structure form in the Baltic Sea. Such a condition is a rather long period of strong breezes. In that case all the superjacent water up to a certain depth, which is a function of the wind force,

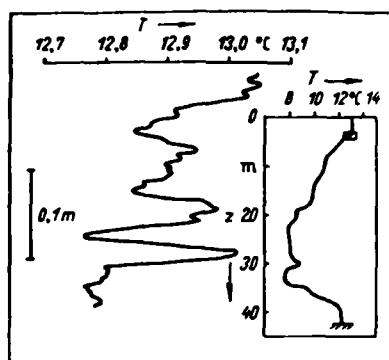


Fig. 13. Temperature profile of a near-surface temperature discontinuity layer, which is characterized by marked mixing (measured on 18 June 1981 in the Arkona Sea)

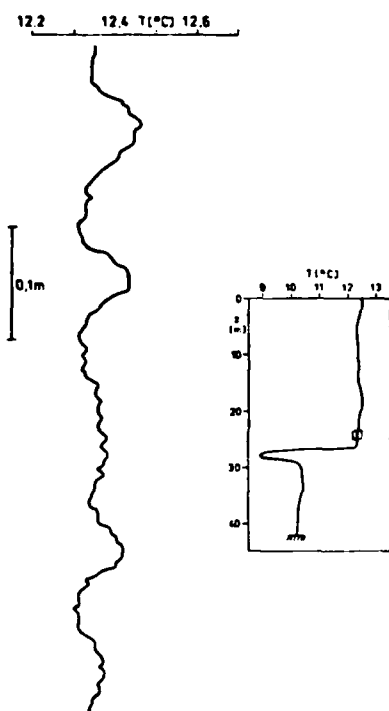


Fig. 14. Active layer structures in an apparently homogeneous depth area in the Arkona Sea (measured on 18 June 1981)

is mixed. The lower limit of this wind-mixed layer in the shallower sea areas, for example, in Mecklenburg Bay, is frequently a discontinuity layer only a few centimeters thick without any internal structure with very sharp temperature gradients. In Mecklenburg Bay, where the summer temperature stratification is still being intensified by the haline stratification, temperature gradients of over 110 K/m and salt gradients of over 200°/00/m were found (fig. 12). In the open Baltic Sea, where the density stratification in the top layer is determined only by the temperature, the gradients in such discontinuity layers are smaller. They are in the area of 20 to 40 K/m. Elements of active mixing were also found considerably more frequently than during calm weather in the discontinuity layers. The cause of that was probably to be sought in the direct entry of kinetic energy into the discontinuity layer as a result of the strong



mixing from the wind. This assumption is also supported by the observation that in practically all temperature discontinuity layers, which form on days which are calm or only with light breezes in depths of a few meters from the heating of the water surface and the slight, but continuous mixing due to the wind near the surface, a marked active mixing was observed. Fig. 13 shows a section from such a temperature discontinuity layer, which exhibits only a few tenths of a degree of overall temperature change.

Another important result which was obtained with the MSS microstructure probe is the knowledge that, even in apparently homogeneous water layers in the Baltic Sea, fine, sharp boundary layers and active layer structures can exist which are not recorded with the conventional STD probes and are practically overlooked. These stratification elements, which were very often detected in the top layer areas as well as in greater depths, have great importance for the vertical water exchange, especially in the depth range above the summer temperature discontinuity layer. They are in most cases identical with the boundary layers of various bodies of water in the depth range above the summer temperature discontinuity layers, with the lower limit of the wind-mixed top layer, if the latter does not extend to the discontinuity layer. Fig. 14 shows an example of stratification elements in an apparently homogeneous water body.

These few selected results provide an idea of the variety and the complexity of the structure of the thermal and the haline density stratification in the Baltic Sea. But they also show that it is necessary and possible to gain a better and better understanding of the complex processes at work in the sea with the means of modern oceanology, and thus create a foundation for a still more effective utilization of its resources.

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